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Aerial Photography to Detect Nitrogen Stress in Corn

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Summary

Economic and environmental benefits can result from improved nitrogen (N) management in corn (*Zea mays* L.) production. This research project was conducted to determine the utility of aerial photographs to detect N deficiency in a crop canopy caused by natural soil variability and variable fertilizer N application rates. Chlorophyll meter readings and digitized aerial photograph data were compared to corn grain yield and stalk nitrate concentrations from a 60-ha field in Central Nebraska. In addition to natural field variability, 30.4-m long treatments were imposed through the center of the field by applying fertilizer at rates of 0, 56, 112, 168, and 224 kg N ha^{-1}. Grain yield, chlorophyll meter readings, photographic brightness and stalk nitrate samples were collected. Despite a significant effect from fertilizer treatments, chlorophyll meter readings did not correlate well with grain yields. The brightness of the red component in a digitized color photograph showed a significant inverse relationship ($r^2 = 0.42$) with grain yield. Stalk nitrate concentrations at harvest, when compared to red brightness from the digitized photograph, provided a better confirmation of N status than grain yield. Aerial photographs appear to be capable of detecting management induced variability as well as reduced yield portions of a field that result from natural variability.

Key words: Nitrogen, chlorophyll meter, Zea mays L., remote sensing, stalk nitrate, aerial photographs.

Abbreviations: N = nitrogen; GPS = global positioning system.

Introduction

Economic and environmental benefits from improved N management in corn can frequently be enhanced by using real-time methods to evaluate management practices. Tissue testing is one technique that can provide valuable information on the crop's N status.

Current tissue tests for N used in production agriculture require sampling specific plant parts and making interpretations according to generalized criteria. It follows that tissue samples can be no more representative of a field than the plants that are sampled. Therefore, if soil properties or other conditions (climate, disease, insects, etc.) change spatially or temporally, it may be difficult to collect and analyze the appropriate number of samples that permit identification of N stressed areas in a field. This limitation is because of the labor requirements, time constraints, and analytical expenses.

Chlorophyll meters have recently been introduced as a tool to quantify N status. Application of this technology extends to monitoring the dynamics of N transformations in soil and assessing N availability to crops. Researchers have shown that chlorophyll meters are capable of detecting N stress in corn (Pickielek and Fox, 1992; Schepers et al., 1992; Wood et al., 1992; Blackmer and Schepers, 1995). Chlorophyll meters measure light transmittance through a leaf and provide rapid results without the expenses of laboratory analysis. However, interpretation and application of chlorophyll meter data are hindered by the problem of obtaining a representative sample from a potentially variable field.

Canopy reflectance measurements integrate many factors influencing the general health of the crop. Reflectance measurements can range from those that deal with individual leaves to those that encompass an entire field, depending on the configuration of the sensor and distance from the crop. In any case, some ground truthing and analytical results are required to interpret reflectance images, whether they be scans from a spectroradiometer or an aerial photograph. Nonetheless, reflectance measurements potentially offer a more rapid and less expensive assessment of growing conditions than is possible with traditional chemical analysis using leaf tissue or plant sap.

Canopy reflectance in the visible and near infrared wavelengths has been shown to detect N deficiency in corn (Walburg et al., 1982; Blackmer et al., 1995). This permits rapid evaluation of larger areas than is realistically possible with chlorophyll meters or traditional tissue testing procedures. Another advantage is that reflectance techniques can be automated for use on high clearance vehicles.

Aerial photography is one of several techniques to record canopy reflectance. Researchers have been able to detect various types of stress in different crops by use of aerial photography (Colwell, 1956; Wildman, 1982; Jackson, 1986). More specifically, research conducted on N response trials has demonstrated that aerial photography can be a good indicator of deficiency in corn (Blackmer, 1995). The benefit of an aerial photograph is that an entire field can be monitored with high resolution and minimal concern for changing light conditions during the time when measurements are taken. Photographs permit identification of potential problems for even small areas within a field. When coupled with GPS technology, these small areas could be located and treated.

The objective of this study is to evaluate aerial photography as a technique to detect N deficiency in a crop canopy caused by natural or fertilizer induced variability.

Materials and Methods

Corn was planted in late April, 1993 in a 60-ha field near Shelton, Nebraska at a rate of 70,000 kernels ha^{-1}. Nitrogen fertilizer rates (0, 56, 112, 168, and 224 kg N ha^{-1}) were applied as anhydrous ammonia to randomized end-to-end plots that were 12.2-m wide (16 rows at 76-cm spacing) by 30.4-m long and replicated four times. The crop was approximately 30-cm tall at the time of N application. An adjacent strip 12.2-m wide received a constant rate of 106 kg N ha^{-1} (recommended amount based on soil analysis) as anhydrous ammonia.

Chlorophyll meter readings were collected at the R3 (milk) growth stage (Ritchie et al., 1986) by taking two sets of 30 readings using a Minolta SPAD-502 chlorophyll meter[1]. A color aerial photograph (Kodak Gold ASA 400 film) of the entire 60-ha field was taken from an airplane (altitude of ~1500 m) on a clear day when the corn was at the R4 (dough) growth stage. The image was digitized and then rectified using coordinates of 9 landmarks determined with a GPS and ERDAS software. Pixel size was adjusted to one square meter. Average red brightness of the center group of seven by seven pixels was used to represent each plot. Red brightness on the film is determined by light exposure on the film from wavelengths around 600–700 nm.

Grain yields were determined by hand harvesting 15.2 m segments from two rows in each plot. Grain yields were adjusted to 155 g kg^{-1} moisture. Stalk samples consisting of a 15-cm section immediately above the upper crown roots of 12 plants per plot were collected after harvest. Stalk segments were coarsely ground dried, finely ground (1.0-mm sieve), and analyzed for nitrate-N concentration using automated wet chemistry procedures.

[1] Mention of trade names or proprietary products does not indicate endorsement by USDA, and does not imply its approval to the exclusion of other products that may also be suitable.

Results and Discussion

Differences in grain yield were measured for plots that received varying amounts of N fertilizer (Fig. 1). Variability in yield response to each N treatment made it difficult to identify the optimal N rate. Reasons for the differential responses to fertilizer are attributed to variability in the quantity of available N supplied by other potential sources and the influence of various other yield-limiting factors. In that replications were as far as 400 m apart, differential response to N fertilizer is expected. Variability in crop response to N fertilizer was even observed within the long plots. Rows 4 and 13 of the 16-row wide plots used for hand harvesting had an average yield difference between the two segments within each plot of 0.75 Mg ha^{-1}. Differences between subsample yields were greater than expected considering that each subsample represented an area larger than is typically measured for hand harvest.

Chlorophyll meters have been shown to be an effective research tool to detect an N deficiency in corn (Piekielek and Fox, 1992; Schepers et al., 1992; Wood et al., 1992; Blackmer and Schepers, 1995). The above studies generally showed a strong correlation between chlorophyll meter readings and grain yield. These findings based on plot research are in contrast to the field scale results of this study that showed chlorophyll meter readings and grain yield were poorly correlated (Fig. 2). If the yield variation in response to N fertilizer was a result of differences in N availability from sources other than fertilizer, then the chlorophyll meter readings should have detected a corresponding difference in crop N status. One would normally expect a close correlation between relative crop N status at the R3 growth stage and relative yield because of the short time between these events (<30 days). The poor relationship between chlorophyll meter readings and grain yield suggests that either the sampling methods were

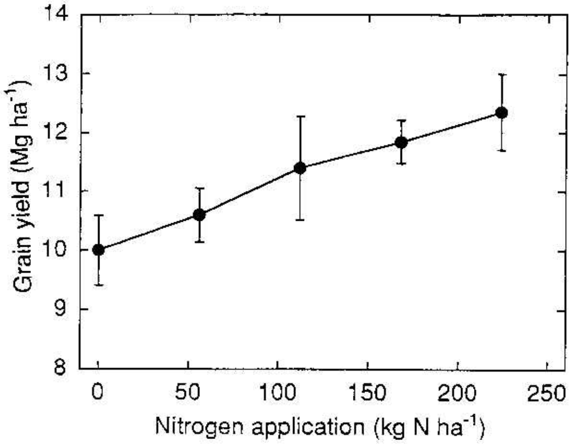

Fig. 1: Corn grain yields of hand harvested plots receiving different amounts of N fertilizer.

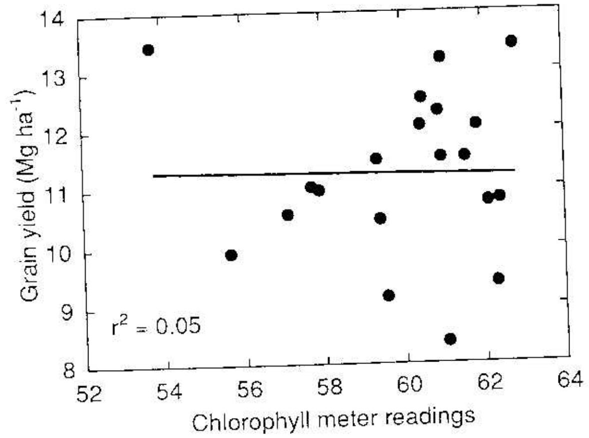

Fig. 2: Relationship between chlorophyll meter readings at the R3 growth stage and grain yield.

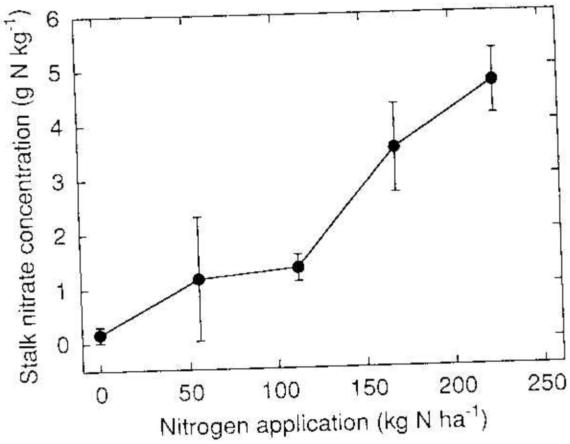

Fig. 3: Stalk nitrate-N concentrations for corn plots receiving different amounts of N fertilizer.

not adequate for either yield or chlorophyll content. Other possibilities are that factors such as disease, N loss, nonuniform N fertilizer application, or plant population affected grain yield. The wide range in grain yield for chlorophyll meter readings above 59 indicates that many factors other than N affected yields (some yields were higher than expected as well).

When available N is present in excess of crop requirement, corn often exhibits luxury consumption by continuing to take up N even though no response occurs. Because chlorophyll meter readings do not generally detect luxury consumption, a late season test of crop N status would be helpful to evaluate N management practices. Determining stalk nitrate-N concentration at harvest is a test that has been used to quantify crop N status of corn at the end of the growing season (Binford et al., 1990). The test is based on the concept that excess N availability in corn is likely to be associated with luxury consumption during the growing season. Extensive evaluation of the late season stalk nitrate test has shown that it is generally able to differentiate between where crop N is adequate and where it is excessive (i.e., luxury consumption) (Binford et al., 1990). The implication is that stalk nitrate-N concentrations above an adequate range are probably caused by excess fertilization, which is known to contribute to nitrate contamination of ground water.

Stalk nitrate-N concentrations in this study showed differences in N status between treatments. Even within a given N treatment, considerable variation in stalk nitrate-N concentration was noted, especially in treatments receiving >112 kg N ha^{-1}. Nitrate-N concentrations above 1800 mg kg^{-1} (Binford et al., 1992) typically indicate that yield was not limited by N availability (Fig. 3). Therefore, high concentrations of stalk nitrate-N minimize the possibility of N deficiency causing the fluctuations in yield noted in Figure 1.

Another method used to detect stress in crops is through analysis of aerial photographs. Photographs can be digitized so that the brightness of each pixel within the photograph is qualitatively indicative of the light reflecting from a given area on the landscape. When combined, the brightness of these pixels generates a digital image that mimics the photograph. This process makes it feasible to compare the brightness of an individual pixel or group of pixels with a designated ground-based measurement.

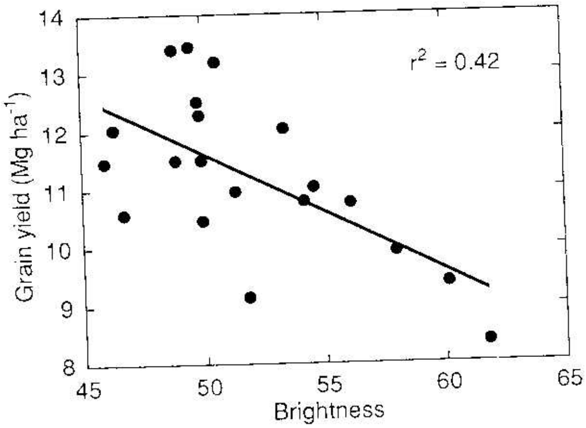

Fig. 4: The relationship between red brightness from a digitized photograph and grain yield.

Digital analysis of the aerial photograph taken at the R4 growth stage showed a significant relationship between red brightness and grain yield (Fig. 4). Because this relationship uses the same yield data as used in Figure 2, it raises questions about the reliability of the chlorophyll meter data. Perhaps the hypothetical problem with the chlorophyll meter data is associated with where on the plant the two types of data are collected. In the case of the chlorophyll meter, the ear leaf was monitored. In contrast, the digitized field image primarily represented the upper portion of the canopy. Perhaps a better relationship with the photograph could have been achieved if the yield measurements were made on the same 7 by 7-m area digitized from the photograph. Aerial photographs have the advantage over ground sampling methods in that the number of pixels represent the number of observations. Automated image analysis permits the user to design the shape and size of the field areas to be compared.

Another technique for examining the ability of the photograph to detect N deficiency is to compare the brightness of reflected light from a plot for a given N treatment with that for an adjacent plot receiving a constant N rate (assumed to be adequate for maximum yield). In this case, the comparison was a field strip receiving a constant rate of 106 kg N ha^{-1} (based on soil testing data) (Fig. 5). The brightness for each N rate was adjusted by comparing the brightness value to the adjacent area, which makes this data specific for this field. Brightness differences observed for the 0 and 56 kg N ha^{-1} treatments and not the higher treatments is consistent with the initial fertilizer recommendations of 106 kg N ha^{-1} and the stalk nitrate data (Fig. 3). Initial soil recommendations, stalk nitrate concentrations and image brightness values all agree with each other, but do not agree with the yield data. This raises further questions about the value of the hand harvested yield estimates.

In an attempt to identify and understand the reasons for the spatial variability shown in digitized images, an area identified as deficient in the photograph was hand harvested. In the photograph, the selected location appeared to have a recurring pattern in the severity of deficiency at 16 row intervals. Field sampling showed that both grain yield and stalk nitrate-N concentration at harvest demonstrated a somewhat similar pattern (Fig. 6). The N fertilization application was made with an eight row applicator. The applicator had 9 knives but the distribution manifold had eight outlets. Fertilizer from one port was split between the two outside knives. Direction of travel during application was reversed so any variation in application rate is expected to be a mirror image of the adjacent eight rows. The pattern could be somewhat confounded by planting and other field operations which were performed with 12-row equipment.

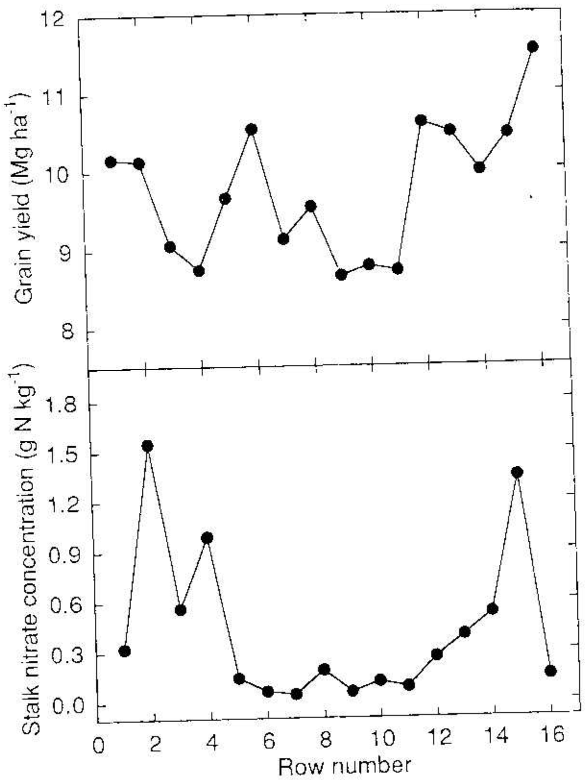

Fig. 6: Stalk nitrate-N concentration and grain yield from consecutive corn rows in a portion of the field identified as N deficient in the photograph.

Conclusion

Aerial photographs make it possible to identify atypical or possibly N deficient areas within a field. This study showed considerable variability associated with yield response to N fertilizer treatments which complicated photographic verification. Stalk nitrate-N data helped confirm the photographic capabilities of identifying N deficient areas. Chlorophyll meter readings taken at the R3 growth stage were poorly correlated with grain yield in this study. Photographic data collected at the R4 growth stage were more highly correlated with grain yield than chlorophyll meter data. These findings may be the result of more intensive sampling and evaluation permitted with the photographic technique. Overall, the photograph provided the best indication of crop N deficiency and permitted evaluation of the entire field at relatively little cost.

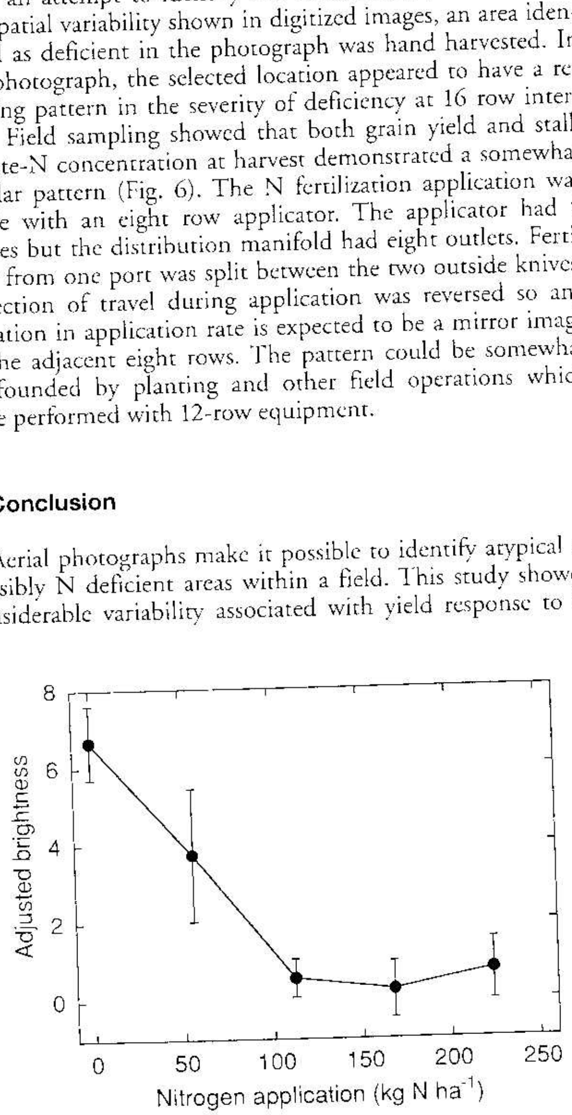

Fig. 5: Difference in red brightness between an adequately fertilized reference area and plots receiving various rates of N fertilizer.

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